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THESIS

A SOFTWARE ARCHITECTURE FOR A COMMANDER'S DISPLAY SYSTEM

by

Rodney M. Adams

March 1987

Thesis Advisor Michael J. Zyda

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One of the main tasks of a command and control system is to present commanders with a basis for complete his tactical situation. A system that transforms a large volume of data into a comprehensive picture that can then be used for situations assessment can aid the commander's decision making process. A system capable of performing this task has, until recently, required the dedication of vast amounts of computer resources.

This report suggests a structure for a commander's display system that relies on recent advances in computational power in the form of a small, high-powered, dedicated graphics system. A prototype system is included as part of the research effort.

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A Software Architecture For A Commander's Display System

by

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Lieutenant, United States Navy
B.S., United States Naval Academy, 1981

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ABSTRACT

One of the main tasks of a command and control system is to present commanders with a basis for complete his tactical situation. A system that transforms a large volume of data into a comprehensive picture that can then be used for situations assessment can aid the commander's decision making process. A system capable of performing this task has, until recently, required the dedication of vast amounts of computer resources.

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I. INTRODUCTION

A. STATEMENT OF THE PROBLEM

In the past thirty years, there has been a revolution in the way that armed forces are organized and equipped to fight. The advent of guided missiles, computer data networks, and supersonic aircraft has both expanded the commander's horizon and attempted to give him the ability to keep track of events that directly affect his environment. Since the problem is so complex, a large volume of information must be obtained in order to describe the situation. Frequently this information is generated with no convenient way for commanders to access it. There can, therefore, be a significant lag between the sensing of events and the understanding of the effects of those events. This lag can be aggravated by situation display systems that become overloaded in a stressed environment.

Nearly every level of the military organization has experienced a situation where real-time data becomes nearly useless because it has to be processed in an inappropriate manner. The term inappropriate is used because it covers a wide range of problem situations. It includes the manual plotting that is still used on most ships, the use of digital computers where the output is a ream of alpha-numeric data and the use of monochromatic graphical displays to show a picture of a complex situation. Each of these ways of producing information can be useful up to a certain situational density, but they do not always allow the commander to evaluate his situation and determine his most appropriate response. Since there are systems available today that can process and display vast amounts of information in real-time it is imperative that an effort be made to reduce the information gap by exploiting their capabilities. In order to maintain a qualitative advantage in any future conflict, we must aggressively pursue the use of the best available technology that makes important information as accessible as possible.

B. SUGGESTED SOLUTION

One of the most promising recent developments in the area of turning vast amounts of data into usable information has been the production of real-time graphics workstations. The term real-time implies that complex pictures can be generated so rapidly that a display can be refreshed at a rate fast enough to appear continuous.

There are many applications for these machines, but the one that will be focused on in this study is an ability to turn raw data into an understandable picture of the tactical situation. There are some current systems that can produce situation displays rapidly; but, because of the limitations on memory and processing power which were available when they were built, many tradeoffs had to be made [Ref. 1: p. 3-1]. Current technology has increased the available resources by making dramatic improvements in processing power, memory, and storage. While the capabilities of computers has increased, the cost of these systems has decreased significantly. This technological revolution can be utilized to remove some of the limitations and costs associated with the previous generation of display systems.

C. SPECIFIC ADVANCES

In the past five years, the amount of processing power and memory available in a small computer package has increased dramatically. With the advent of advanced 32-bit microprocessors, high density fixed disk drives, inexpensive memory chips, and very large scale integrated circuits (VLSI), it is now possible to put mainframe power in the hands of individuals. In the area of computer graphics, these advances have made possible high-resolution, real-time raster scan displays. It is now possible for system designers to produce workstations designed for single users that have multi-tasking capabilities. The power of these workstations can be well applied by using them to help military staffs integrate a large quantity of data into an understandable tactical picture.

Since each display unit has its own processing ability, the picture can be controlled completely by the user; he can display the pertinent information in a manner best suited to his needs. The user can change scale, reduce the clutter of the display, focus on a particular area of interest, and obtain additional information that may not always be displayed. With a careful design, this control can be exercised immediately and in a fashion that is easily learned. Since one of the major tasks of a commander's staff is to ". . . present the commander with a comprehensive and coherent basis for accurate situations assessment and timely tactical decisions. . . ." [Ref. 2: p. 7], it is a natural evolution to apply the capabilities of these advanced workstations for command and control systems.

D. ADVANTAGES OF STATE OF THE ART WORKSTATIONS

By using an appropriate high performance workstation, it is possible to have the following effects on command and control.

1. It can increase the commander's understanding of the environment. With the use of a color picture to condense the vast amount of sensor input, the most important events can be readily apparent while those of lesser importance are still available.
2. It can allow the use of distributed networks of information sharing and give the commander much greater flexibility as to where he needs to be to have access to vital reports. The small size and comparatively low cost of these workstations is what makes this distributed idea possible.
3. By distributing much of the processing that was previously performed by centralized systems, the responsiveness of the overall system in times of crisis can be improved.
4. Due to the tremendous improvements in the price-to-performance ratio in computing systems in the last few years, it is now possible to produce a command display system that is less expensive to operate and that is much more capable than currently deployed systems.

This study describes a prototype display system which utilizes an available high performance workstation to produce a comprehensible display from a stream of contact reports.

E. ORGANIZATION

The remainder of this study is organized in the following manner. Chapter II discusses the system level software structure for the project. Chapter III describes the methodology used for the display system, and discusses the selection of the contact symbols the system uses. Chapter IV discusses the user interface that was developed as part of the project. Chapter V is a system users guide, and Chapter VI provides the conclusions reached from the project and discusses opportunities for future work. A copy of the software developed for this project can be obtained from Dr. Michael Zyda in the Computer Science Department of the Naval Postgraduate School.

II. SOFTWARE STRUCTURE

A. OVERVIEW

The structure of the software in a large computer program is an important part of the system. Decisions that are made at the beginning of the process of choosing the structure influence the course of the entire project. This chapter discusses the architecture of the system level programs for the Commander's Display System (CDS) project. Specific sections of the chapter include a discussion of the operating system that was chosen and its particular capabilities, a description of the communications routines that were used, and a description of the example computing network on which the system has been implemented.

B. SYSTEM LEVEL

1. Operating System

The system level software of the CDS provides the necessary utilities to allow several machines to be linked together. This ability is very important for a system that is intended for usage in a command and control environment. No system for that environment can be a stand-alone unit; it must be able to share data with a wide variety of other users. This ability is not automatic, in fact a large percentage of the effort in designing complex information systems goes into the building of interfaces. This task can be made easier by the selection of a common operating system for the computers involved. The UNIX operating system was chosen for this project for several reasons.

- It is a widely used operating system, especially on mini-computers and workstations.
- It provides a rich variety of utilities that make programming easier and less time consuming.
- It supports common network interfaces like Ethernet, Telnet, and File Transfer Protocol (FTP)
- It provides a means to directly connect machines by the use of sockets. These are direct paths between two computers that are connected by a network.
- It allows for the possibility of transfering the software to a wide range of different computer systems, since it is such a popular operating system.

The specific version of UNIX that was chosen for the project is UNIX System V. This system was chosen primarily because it is the system used by the Silicon

Graphics, Incorporated IRIS workstations available in the Graphics and Video Laboratory of the Naval Postgraduate School. Another benefit from the selection is that System V supports some key features which not all versions of UNIX have. Some of these features were used for the CDS program and are discussed in detail in a later section.

a. UNIX Availability

The UNIX operating system has become a de-facto standard in mid-range computing systems. It is the system of choice for many workstation type systems including, but not limited to Sun Microsystems workstations Hewlett-Packard 9000 series workstations, and Silicon Graphics IRIS workstations. The system has been successfully implemented on the full range of computing systems available today including PC's, workstations, departmental mini-computers, mainframes, and even supercomputers [Ref. 3: p. 18].

By selecting a system that is widely used, several benefits can be obtained. One advantage is the portability of the software that is produced. With minor modifications, for example, the specific graphics commands, the software can be run on a variety of different machines. Some tradeoffs, though, need to be made if less powerful systems are chosen for the implementation. This portability prevents the system from being tied to a particular piece of hardware and enhances its potential usefulness. The use of UNIX appears to be spreading rapidly which implies that improved computers will support its use [Ref. 3: pp. 207-212]. Another second benefit that comes from using a commercially wide-spread system is that the marketplace can enforce standards. Due to the significant investment that is made in system specific software, popular operating systems develop some needed inertia. Customers resist changes that void their investments, therefore the UNIX system should be around for many years to come.

b. Tool Availability

A third advantage derived from the use of a popular system is the large existing library of programs, utilities and routines. The savings in programming time using these pre-existing tools can be substantial. This benefit has become more and more useful as the techniques of structured programming become the rule rather than the exception. By making use of existing modules, system designers and programmers can spend a greater percentage of their time in adding new capabilities rather than repeating past efforts.

c. Communications

In addition to the above benefits, the use of a common operating system, like UNIX, allows for easier computer to computer communications. Computers that use the same operating system can more easily be linked together to form a system. The CDS demonstrates this networking ability by having one computer provide contact position reports and identification data while another computer displays the picture which represents the data. The ability to communicate data rapidly is very important for a computer that is part of a command and control system. It is important for the commander to acquire all available information in a short period of time so that the decision making process is fully supported.

2. System Routines

a. Sockets

A *socket*, in UNIX terminology, is a means of allowing machines that are connected via a network to use each other as logical input or output devices. Sockets, therefore, can provide a communications path between the machines. Although the UNIX system aids in communications by allowing the use of sockets, it does not make it easy to access this capability. This difficulty has been nearly eliminated by a set of routines that were developed by LCDR. James Manley at the Naval Postgraduate School. The programs, called netV.c and net4.2.c (named for UNIX System V and Berkeley UNIX system 4.2 respectively) define routines that put all of the required system calls into a single command for establishing a socket between machines that are connected via a network. In order to establish this communications link between machines, there must be a program which accesses the socket available on each computer. One process is designated as the *server* and must be started first. Once that process has opened its end of the socket, another process on a different machine can be started as a *client*. Once the socket has been obtained by both processes, either one can send or receive data by calling the UNIX library routine *write* to send and the routine *read* to receive. A program that writes to a socket continues processing, but one that attempts to read from the socket waits at the *read* line until there is something to read. With this scheme, the socket is merely another logical input or output device. [Ref. 4].

b. Shared Memory

On some versions of UNIX (notably UNIX System V), another useful communication tool is possible. This tool is called shared memory. It is the ability for two different programs (sometimes known as processes) to use the same memory locations. This means that different processes running on the same machine can communicate with each other. This is a very powerful tool for allowing rapid communication between different processes. This can allow separate programs to perform the tasks required and it can be used to greatly improve the efficiency of the overall system. A set of routines developed locally allow the easy use of shared memory.

c. Semaphores

A third function that some versions of UNIX, including UNIX System V, support is called a semaphore. As the name implies, these are used as signalling devices. The purpose of semaphores is to allow the programmer to force the system to utilize shared resources in the manner in which he wants them to be used. With a semaphore, a programmer can prevent a background process from consuming CPU cycles until it is time for the process to perform an action. It is nearly always possible to prevent processes from doing anything until a certain condition is met, but this is often a "busy wait" type situation. In a "busy wait" the process is constantly checking the specified condition to see if it is met, all the while consuming valuable CPU time. On the other hand a process trying to obtain a semaphore can wait at a chosen point in the program until the semaphore becomes available. While it is waiting, the process consumes no CPU cycles. [Ref. 5: pp. 188-190]

C. APPLICATION LEVEL

1. Applied Use of Sockets, Shared Memory, and Semaphores

a. Socket Via Ethernet

The capabilities provided by the system and the Manley routines were used in the CDS to provide a real-time communications capability. In order to prevent the graphics display from being interrupted by a requirement to listen for traffic, a communications program was developed to run in the background of the machine or machines that were being used for displays. This program continuously monitors a selected socket, and when data is received via that socket, it stores the data in a buffer. In order to ensure that the server process does not overwhelm the client with data, the server waits each time it writes to the socket to receive a confirming message from the the client informing it that the data has been received.

b. Shared Memory Between Processes

The client process then uses a shared memory segment to signal the display program that new information is available for reading. At this point the communications process attempts to acquire the semaphore so that it can send the buffer to the main program. If the display program is ready for the new information, the semaphore is acquired and the buffer is transfered into a shared memory segment. If the display process is busy, the communications process goes to sleep until the semaphore is released by the main process. This program structure provides the display system with an ability to receive updates on a variable time schedule rather than requiring that updates be regularly spaced. This allows the system to respond to communications that may slow down or speed up as situations change in complexity. This arrangement also prevents distracting periods of time when the display program freezes to wait for more data. Figure 2.1 illustrates the way that the various processes were structured to form a system of cooperating programs.

c. Semaphores For Resource Allocation

By using the semaphore device, the majority of the CPU time can be used to process and display the incoming information with a sufficient resource level dedicated to the communications problem. Until the semaphore arrangement was implemented, the display process was slower and the menu interactions took a noticeable period of time due to the fact that the communications process was consuming CPU cycles while it was waiting for the display routine to be ready to receive data.

2. Communicating Processes

a. Information Supplier

The server process is the information supplier. It is assigned the job of generating contact reports, which are then sent via a socket to the machine(s) that are running the CDS graphics display. The purpose of this supplier in the structure of the system is to simulate a stream of data that might be available in a command and control information system. The supplier uses a pseudo-random number generator to produce course and speed changes for the contacts and and then updates their position before sending the data to the information receiver. This supplier provides some flexibility in terms of demonstrating the capabilities of the workstation. It shows what the system can do with a reliable data stream, and what will happen if the data stream is lost. It is also used to provide a variable situation for the display system without the need for a large number of prepared scenarios.

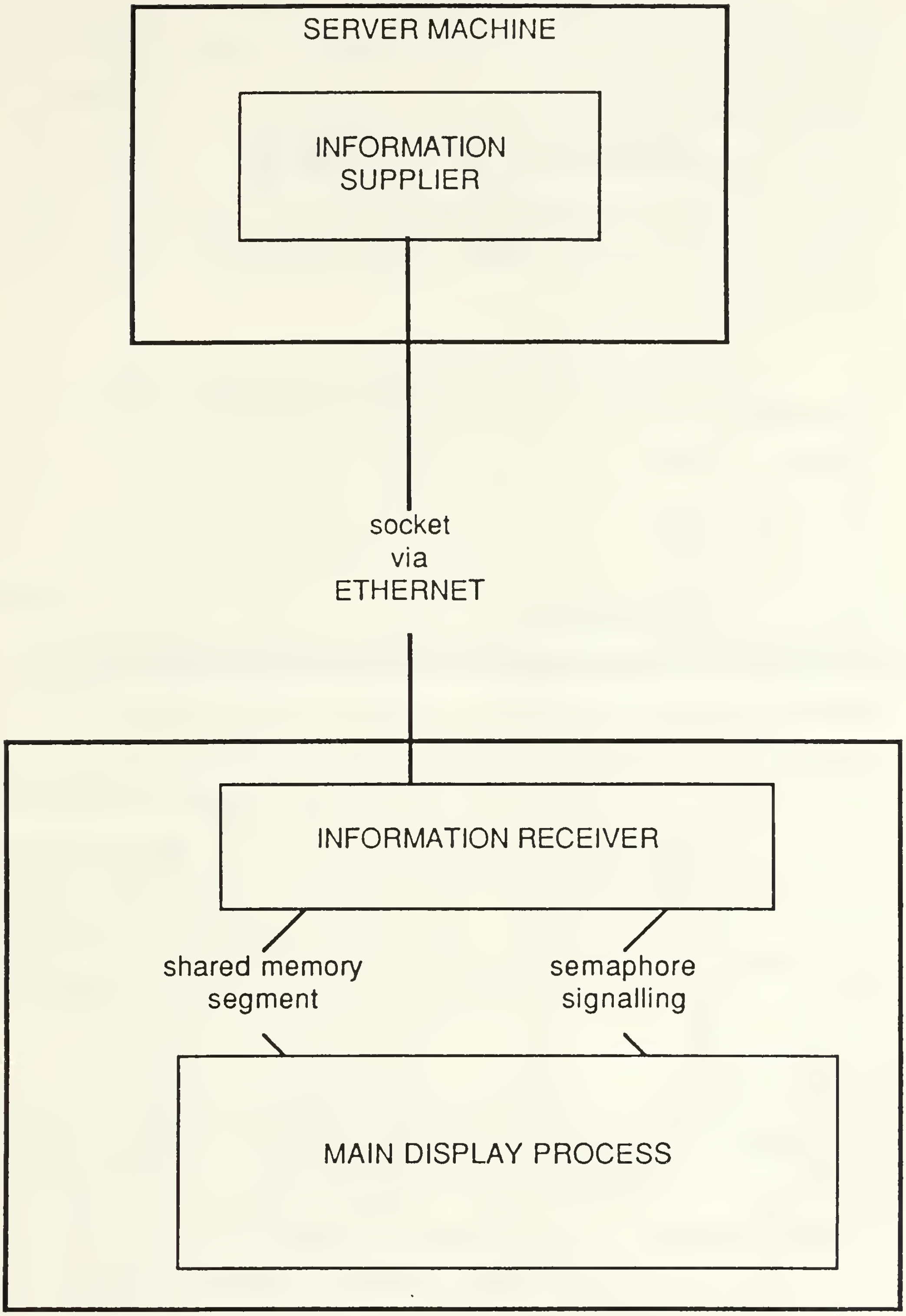


Figure 2.1 Structure of the System Level Programs.

b. *Information Receiver*

Having a separate communications program prevents the main display loop from being vulnerable to the loss of the information sender. With the current software architecture, the sender program can be interrupted and the system will continue displaying contact information based on the last update that was received. To ensure that the operator is aware that the data source has been lost, a warning signal is displayed that indicates how long it has been since the link was lost. This prevents the commander from losing his display while still informing him that the picture being shown is based on aging data.

c. *Example Computing Network*

In order to demonstrate the flexibility of systems configured on a network, the capability of using any one of three information sources and either of two display systems was developed. Figure 2.2 illustrates the small network of computers that were used for this project. The UNIX based VAX on the Ethernet can serve either or both IRIS machines, IRIS 1 can serve IRIS 2 or IRIS 2 can serve IRIS 1. Each of the systems illustrated has a different level of performance. The VAX is a centralized, time sharing type of system. As such, its ability to generate contact updates is somewhat slower than that of the dedicated IRIS machines. However, the VAX has the capability of storing a much larger volume of data than the IRIS's so it, too, has some strengths. In a full command and control system, a centralized computer like the VAX can receive and store contact reports along with information like mapping routines and platform capabilities. The distributed display systems can then access this data and manipulate it without sharing the CPU. IRIS 2 is a "turbo" version of IRIS 1 with a more capable CPU (a Motorola 68020) and an optimized disk drive. Even though these systems have different capabilities, they can still be made to cooperate in a responsive system.

D. SUMMARY

The choice of a widely used operating system like UNIX gives the CDS program the capability of being run on a variety of different machines with only minor modifications. The tools and utilities available with the UNIX system make it an excellent environment for the development of software. Additionally, its use allows the developed system to be connected with other computers to form a powerful and flexible network of communicating machines.

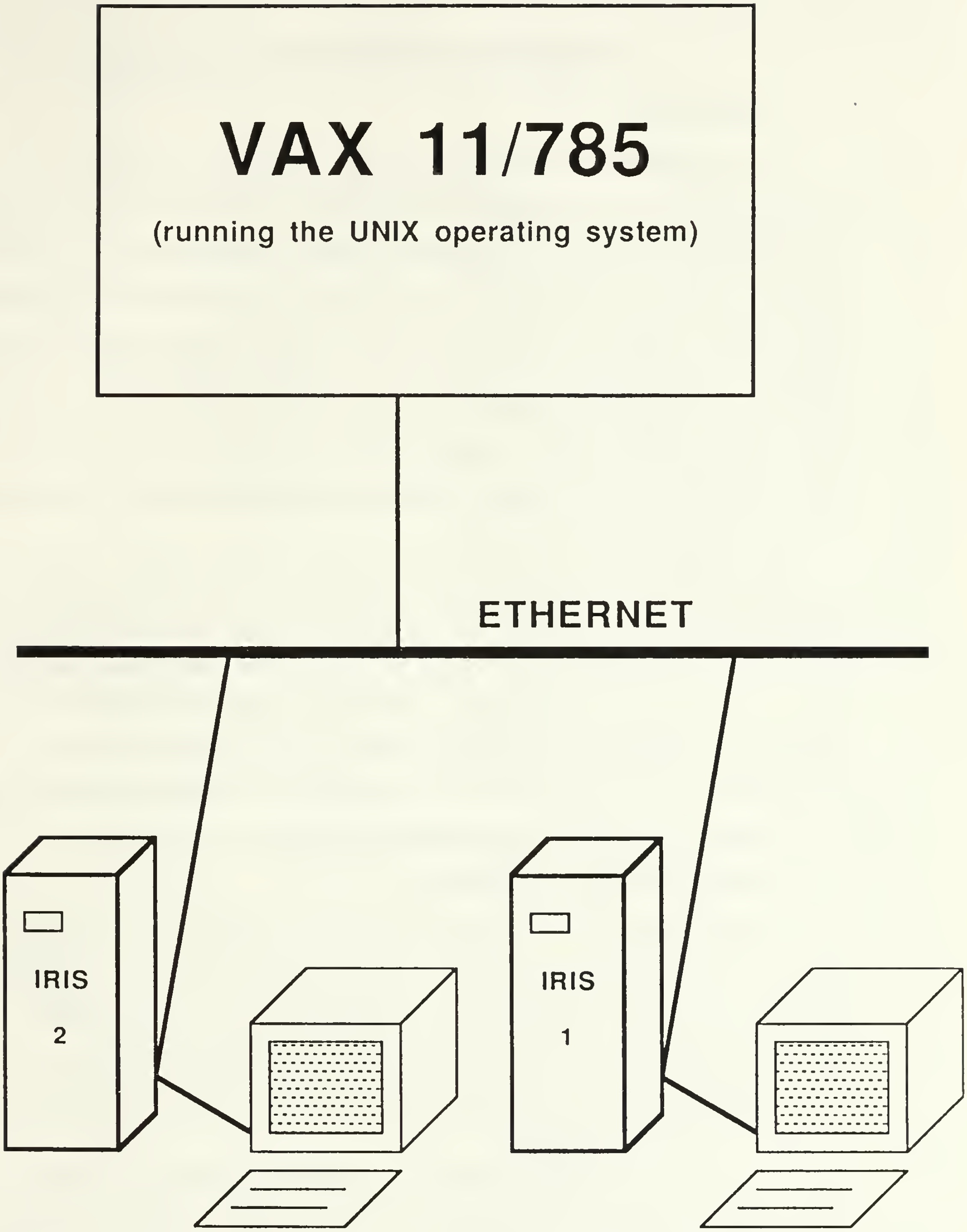


Figure 2.2 Computer Network.

III. DISPLAY SYSTEM METHODOLOGY

A. OVERVIEW

The Commander's Display System was designed to demonstrate the capabilities of a state of the art color graphics workstation to present a clear, timely picture of the current tactical situation. The program performs this function by taking a simulated stream of contact reports and placing symbols representing the type and allegiance of the contacts in a position on the screen that represents their geographic position. The position of each contact is reported relative to a fixed reference point. The system also displays some additional information about each contact in the form of a short alphanumeric modifier and a vector that indicates a best estimate of the contact's course and speed. Other pieces of useful information about the contacts are available to the user at the touch of a button.

The program also makes available options to the display operator for various configurations of the display. Some of these options are symbol size, display scale, display center, and display filters. All of the available options are discussed in detail below. In order to keep this system available for unlimited distribution, all of the data structures were developed specifically for this project and the data used is merely an approximation of the type of data that is available in an operational data base.

B. SYMBOLIC CONTACT REPRESENTATION

1. Influence Of Display Technology

Most display systems currently in use in command centers show information about the current situation by using a set of abstract symbols. These symbols are a convenient means of rapidly conveying a large quantity of information to a trained operator in a compact form. Until very recently, the possible symbol set that could be used was severely limited by the capabilities of the available display devices.

a. Vector Scan Displays

In order to produce clear lines, characters, and symbols, one had to rely on systems based on a technology known as vector or random scan. With these devices, the image to be displayed is encoded as a set of vector endpoints. Each line that is drawn requires the deflection of an electron beam to the next point on a phosphor coated screen. These systems can produce sharp lines and points, however, their ability to create complex shapes is limited by the speed with which the electron beam can be deflected. Additionally, they cannot produce shaded or solid color areas. Since this is the technology that has been used in past display systems, the symbols that have evolved have tended to be simple geometric shapes. [Ref. 7: p. 94]

b. Raster Scan Devices

With state-of-the-art graphics systems, however, a different type of display mechanism can be used to produce a quality picture. This mechanism is known as raster scan, and it is the same basic technology as that used in television sets. A raster scan display stores its picture information as an array of intensity values for each individual picture element (pixel). The CRT beam can then be deflected line by line and need only change intensity to control the image that is displayed. The disadvantage of this method is that pixels can be either fully on or fully off, although the brightness can be varied. If an insufficient number of pixels are used for the screen, a line that is not either horizontal or vertical appears to be a stair step rather than a smooth line. A large number of small pixels on the screen can limit this problem, but until recently, that was very expensive due to the high cost of memory. Reducing the size of the pixels by a factor of two requires four times as many pixels to fill the same screen size. This requires the screen memory to also increase by a factor of four. Fortunately, memory is has become cheap.

To comprehend the phenomenal advances which have occured in the 1980's, one can look at the description of a modern raster scan display in [Ref. 7], which was published in 1984. This book describes a modern system as one with a screen resolution of 512 x 512 pixels with 8 possible values (3 bits) of intensity at each pixel. In contrast, [Ref. 6], which was published in 1986, describes a *good* quality graphics display as one with a screen resolution of 1024 x 1024 pixels with 256 possible values (8 bits) for each of three colors, for a total display memory of three million bits.

With a screen resolution of about 1000 x 800 pixels or better on a 19 inch screen, the pixels are small enough that angled lines appear to be only slightly jagged, rather than stair stepped. This improvement means that raster scan devices can now perform tasks that previously required vector scan displays. Since a raster scan CRT can cost one tenth the price of an equivalent vector display, this capacity is a significant opportunity. Additionally, the number of different symbols that can be shown is virtually unlimited, and filled shapes can be used with ease. If desired, symbol sets of increased complexity and realism can be developed to allow more information to be transfered through the use of pictures.

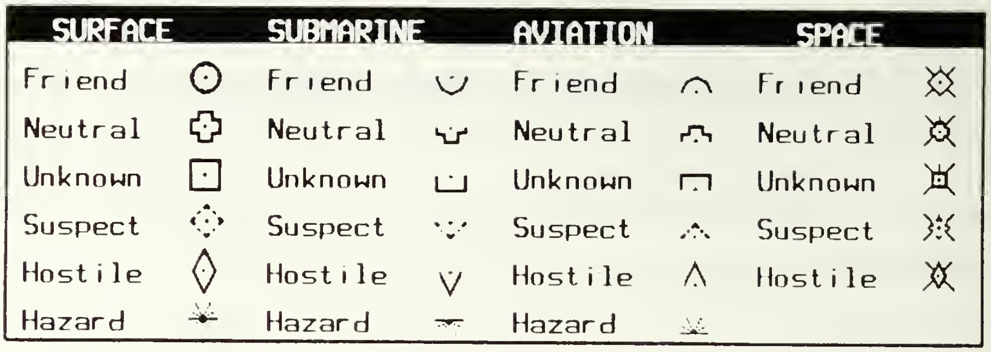


Figure 3.1 Root Symbols and Their Meaning.

2. Symbol Selection Process

Notwithstanding the potential for a completely new symbol set, the contact symbols that were chosen for this system are modeled on the symbols suggested for use by [Ref. 1]. Figure 3.1 illustrates the basic symbol set for contacts that can be encountered at sea. These symbols consist of a set of geometric symbols that are not immediately recognizable for untrained users. For people who have had some experience with tactical displays in the US Navy, however, this set of shapes holds meaning. They are based on the Naval Tactical Data System (NTDS) symbol set and, with some modifications, have been in use for nearly 20 years.

There are those who would argue that the use of simple symbols like these does not make full use of the capabilities of high performance workstations. These systems can just as easily manipulate a set of figurative symbols where a plane looks like a plane, a ship looks like a ship, and a submarine looks like a submarine. The use of these pictorial symbols has shown some promise in improving certain functions associated with command and control display systems [Ref. 8: p. 42].

The Advanced Combat Direction System (ACDS) study recognizes that iconic symbols can be useful. Figurative symbols are recommended for that class of contacts that have not normally been displayed on Navy display systems. Figure 3.2 illustrates the figurative symbols that were developed to handle reports of land contacts that may be of interest to Naval commanders. These icons are intended to be self-explanatory and to give information at a level that is meaningful to Naval commanders and their staffs [Ref. 1: p. 4-43].

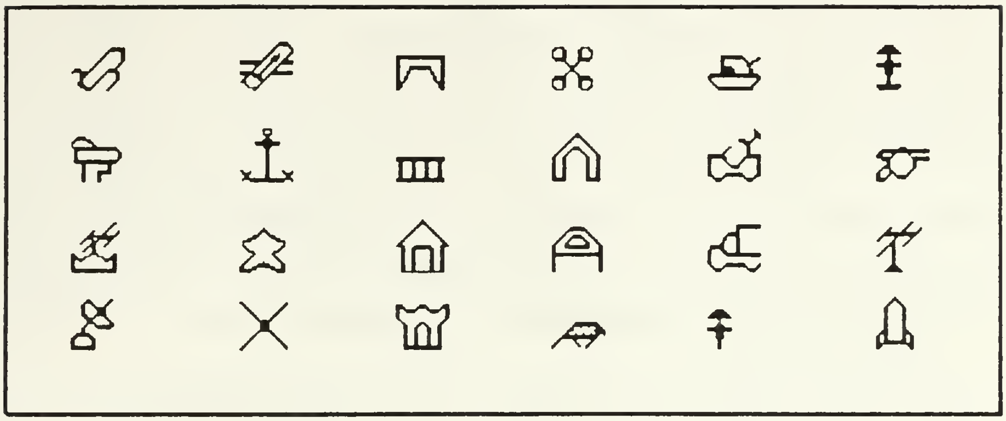


Figure 3.2 Land Contact Symbols.

For the following reasons, the study recommends an evolutionary approach for the contacts which have traditionally been important enough to display on Naval display systems.

- It is difficult to design a set of picture-like representations that illustrate all of the information of immediate interest. That is, one must figure out a way to make an enemy ship symbol look different from a friendly ship symbol.
- Although progress has been made in the field of large screen displays, the physical area available in the command center is a much more severe limitation on the size of the displays than the current technology is. In addition, the size of the threat is growing and a need exists to put even more information on the display. The need, therefore, still exists to have a compact symbol set. This is one of the major strengths of abstract geometric symbols.
- It is not realistic to expect that all levels of command centers will be upgraded to modern display devices. In order to minimize personnel transition problems it is important to maintain some commonality between the contact representations used in all command centers.
- There is an enormous investment in the current set of symbols. They are familiar to a generation of operators and commanders and one cannot overlook the significant retraining effort that would have to occur if a radical change in tactical symbology were imposed.

As a result of the above difficulties with designing a more iconic symbol set, the geometric symbols suggested by the ACDS symbology study form the basis for the contact display in Commander's Display System. [Ref. 1: pp. 2-2, 2-3]

3. Additional Information That Is Normally Displayed

a. Symbol Modifiers

The ACDS symbol set offers some features that are unavailable in the NTDS system. It defines three new basic classes of contacts which were not used. These are Neutrals, Suspects, and Hazards. [Ref. 1: pp. 4-4 - 4-7] provides a thorough discussion of the reasons for these additions to the previous set of symbols. Another extension that is proposed for the ACDS system is the use of alphanumeric modifiers to the symbols. These short codes can impart a great deal of information to trained users in a small space. An example of a modifier that might tell a Naval commander important facts about his threat is the identification of an enemy ship symbol as a KYN. For people who have been through the Navy's warfare training pipeline, knowing that a contact is a KYNDA class cruiser tells him almost all that he needs to know about the threat that the ship presents him. This modifier methodology is used for the Commander's Display System, although the method for choosing the modifier is beyond the scope of the project. For the CDS, it is assumed that the modifier is part of the contact report. Since these modifiers give the commander a large volume of information without taking up much of his display surface, they are normally displayed.

b. Course And Speed Vectors

Once a commander knows what contacts are in his area and where they are located, his next concern is where they are going. The CDS program answers this question in a compact form by computing a speed vector for each contact and drawing it from the contact's location in the direction of its motion. Since there is a wide range of possible speeds from stationary objects to supersonic aircraft, the system computes the length of the speed vector based on the square root of the contacts speed. The length, therefore, is only a relative measure. However, it can show the difference between a very fast contact and one with a moderate speed. These vectors are normally shown for each contact since they meet the test of compact transmission of important information.

4. Symbols As Fonts

The IRIS workstation, like many other high performance computer systems, provides an ability to load special character sets, known as fonts, into random access memory (RAM) for rapid recall. The normal use of this capability is to define different character sets like italic or Greek letters. Since symbols and fonts are both just patterns of pixels, it was determined that the selected symbol set could be defined as a special font. The symbols could then be manipulated with all of the routines that are normally available for moving text around.

a. Font Creation

Two symbol sets based on the recommended set were created for this project. The second set is merely a larger sized version of the first set. A locally developed routine called *fontedit* facilitates the development of a font by giving the user a grid on which to draw the symbols. The user draws the symbol by pressing a mouse button to turn on individual picture elements (pixels). Each symbol is assigned a correspondence character that translates to a value in the ASCII character set. The complete set of bit-mapped symbols is stored in a single file. The font can then be loaded into memory by calling the routine *fontdef* with an integer font name and the appropriate file name as the arguments. The symbol set can then be quickly accessed by calling the IRIS routine *font* with the font name as the required argument.

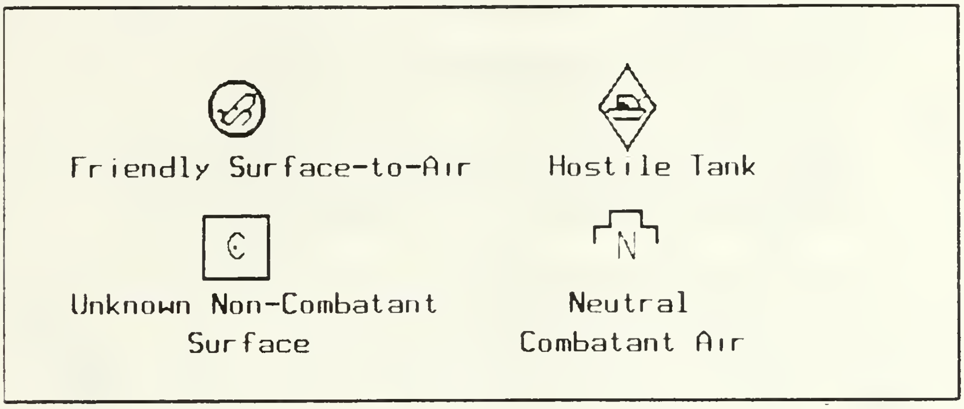


Figure 3.3 Examples Of Combination Symbols.

b. Symbol Combinations

Some of the symbols that were suggested by the ACDS symbology study can be most efficiently produced by combining two distinct symbols. The Commander's Display System provides the capability of placing two special characters in the same location in order to give access to a wider variety of symbols. Figure 3.3 illustrates several of these combined symbols and defines their meaning. [Ref. 1]

c. Font Manipulation

The contact symbols are placed on the screen by calling the IRIS routine *cmov* to position the symbol and then calling the IRIS routine *charstr* to place the symbol in the display buffer. The ease with which this positioning occurs illustrates the usefulness of defining the symbols as special fonts. Another reason that fonts were chosen to draw the symbols is that the size of a font remains fixed even if the scale of the display is changed. This is a desirable trait, since the size of the symbols that was selected is a size which is readable from a reasonable distance. It would be disconcerting if the symbols were to shrink or grow at the same rate as the scale of the display.

C. IMPORTANCE OF COLOR

The CDS project was developed on a computer system that has a high-resolution color monitor. Since the project's set of contact symbols does not depend upon color for information transfer, it is possible to implement the system on a computer with a monochrome display. The use of colors, however, provides some very useful features.

- It allows for redundant coding of contact allegiance. The shape of the contact tells the commander whether the contact is an Enemy, Friend, Unknown, Suspect, Neutral, or Hostile. However, by using different colors for each of these groupings, it is easier to pick out a massing of similar allegiance contacts.
- It allows for easier discrimination of contacts that are displayed close together. Figure 3.4 shows a black and white representation of a system display which is hard to read. A color picture would be more easily understood.
- It provides a mechanism for tying pieces of displayed information to the proper contact. For example, the contact modifiers and the contact track history are displayed in the same color as the symbol. This reduces the possible confusion that may occur if several track histories merge or cross.
- It is used to provide feedback to the user from the menu system. The use of various colors of highlighting keeps the operator informed of the latest menu selection and the currently available options.

The color scheme that was chosen reflects the current standards for the choices of colors for displaying different types of contacts. Blue is used for friendlies and green is used for neutrals. Orange is used for suspect contacts and red is used for the known hostiles. White is used for unknown contacts and cyan is used for hazards. Similar color schemes have shown their usefulness in research efforts like those documented by [Ref. 9]. Due to the lessening of the difference in price between color systems and monochrome systems and because of the inherent advantages of color systems, it is felt by the author that the use of color displays should become standard for command and control systems.

D. SUMMARY

The methodology that is used for the CDS display is to represent reported contacts as geometric symbols which classify the contact in broad categories, for example, friendly surface ship. An additional level of classification detail is provided by short alphanumeric modifiers that are located directly beneath the contact symbol. The contact's course and speed are indicated by a vector pointing in the direction of travel. The use of color codes relating to the contact allegiance ties each of these pieces together and makes the picture easier to quickly understand. Each of these parts of the display give the commander valuable information in a compact form.

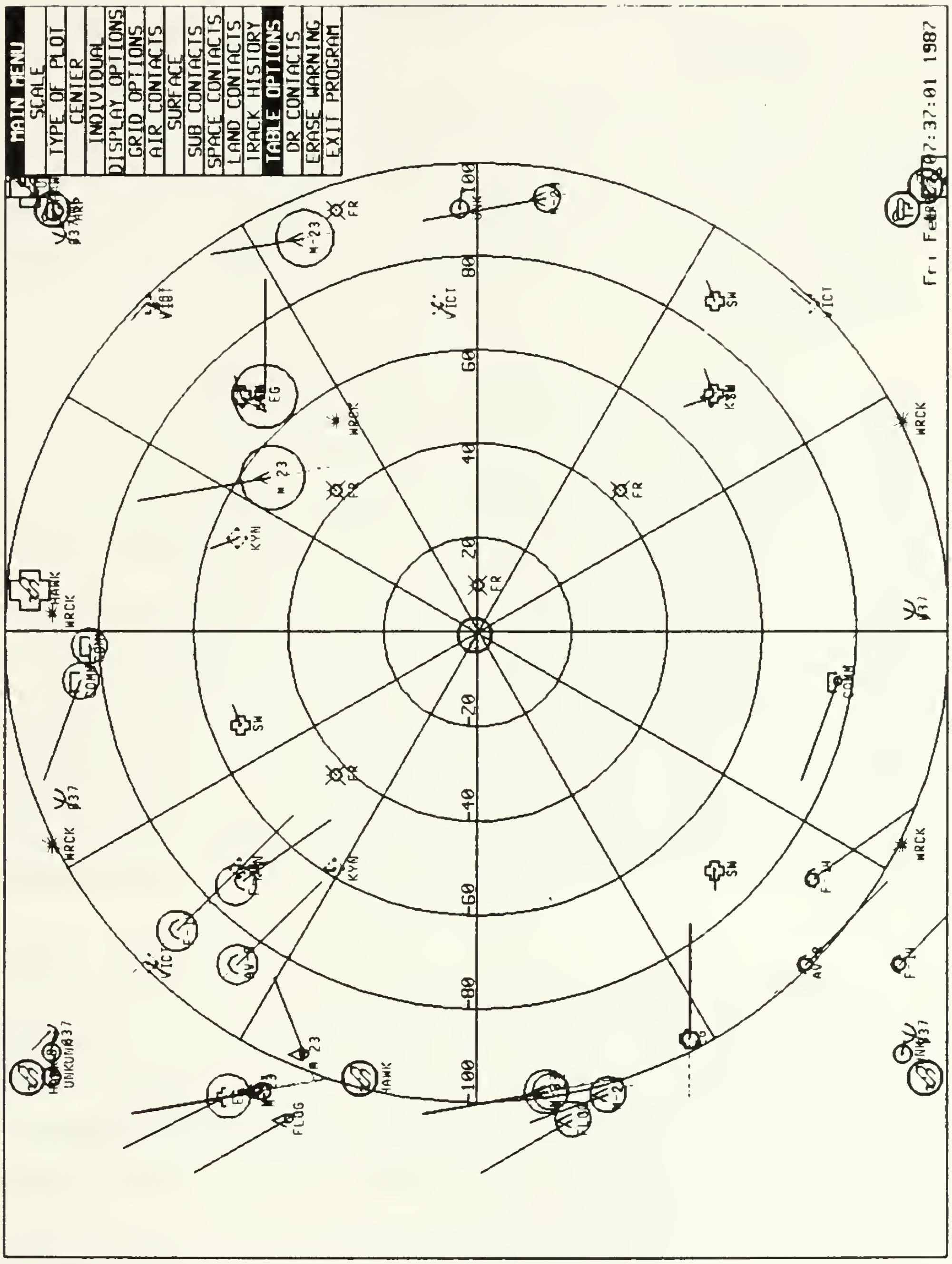


Figure 3.4 Monochrome Representation Of An Actual CDS Display.

IV. USER INTERFACE

A. OVERVIEW

The design of the operator interface for a system designed to support decision makers is important. An information system which presents barriers to its use will not be able to perform its main function. In order to make the Commander's Display System easy to operate, a menu driven system was selected for the user interface.

B. MAIN MENU

When the system is started, the operator sees a picture of the current situation using all of the default settings for the various options. In the upper right hand corner of the display, there is a list of options called the Main Menu. This list defines the major groupings of the various display options. In order to make a selection from this menu, the cursor must be positioned within the boundaries of the menu border. Whenever the cursor is inside of any menu boundaries, it is displayed as a red, horizontal arrow. As the cursor is moved to the different choices, the choice is highlighted. Pushing the middle mouse button while the choice is highlighted selects that choice. When the selection occurs, the choice is then lighted a different color indicating the active selection. A selection in the main menu performs no action. Instead, a sub-menu of actions available from that choice is activated. This sub-menu can be displayed by pressing the middle mouse button while outside the main menu boundaries.

C. POPUP MENUS

All of the sub-menus are what is commonly known as popup menus. These menus are available at the touch of a button; when they are not being used, however, they disappear to allow more of the screen to be used for displaying the information that is of interest. The interaction between the user and the menus is similar to that of the user and the fixed main menu.

To activate the popup menu that is currently available the user presses the middle mouse button. The menu will appear centered on the current position of the cursor, unless the cursor is near the screen boundaries. The cursor can then be moved around the menu and, as it is moved, the choice under the cursor is highlighted. If the cursor is removed from the boundaries of the menu, the menu remains visible but no selections are highlighted. To make a selection, the user points at the desired function with the cursor and presses the middle mouse button when the choice is highlighted. The menu disappears and the function that was chosen is performed. If the menu is activated a second time, it appears with the choice that was made the first time highlighted. If the operator calls a menu and then decides not to make a selection, he can press the middle mouse while the cursor is outside of the menu boundaries. This will cause the menu to disappear with no action performed. Each popup menu has a *return to main* menu function. This selection allows the user to quickly move the cursor from any given point on the screen into the title block of the main menu.

D. JUSTIFICATION FOR MENU SYSTEM

The use of a menu driven system was selected because it offers the opportunity for rapid system competence. With a little familiarization time, new operators should be able to become proficient. Since the menu system provides a list of the available options, operators need not memorize a set of computer commands. Additionally, the menus inform the user which functions are currently active. [Ref. 6: p. 334] This rapid proficiency allows operators to spend their valuable training time learning about facets of their job that are more important than computer system operation. In addition, a system that is easy to use is more likely to be used, and information systems cannot help decision makers if they are ignored. The system is largely self documenting, that is, the menus list the available options; there is little need for further explanation of what each option does.

E. MENU SYSTEM CONTROL

Unlike many menu systems that are currently available, the system developed for this project does not take exclusive control of the CPU during the time that the user is attempting to make a selection. Instead, the system samples the cursor position and checks for a push of the middle mouse button only once each time through the display loop. This method has both advantages and disadvantages. The reason that it was used for this project is that the display of the most recent data was considered to be important. If the menu system took control whenever a selection was pending, there would be a period of time when the display was not being updated. This could cause a problem if the operator of the system took a long time to make a menu selection.

By having the menu system as part of the main display loop, it is possible for an operator to activate a popup menu and allow it to be displayed as long as he desires without interfering with the process of updating the contact positions. Figure 4.1 illustrates the appearance of the display with an active popup menu. The main disadvantage to this method is that when there are many contacts displayed, the system requires a finite time to traverse the entire display loop. This can cause a slight delay in the process of making a menu selection.

Experimentation with the system has shown that about 60 contacts can be displayed on the Turbo IRIS with no perceptible delays in menu response, while about half that number can cause a slight delay on the non-Turbo IRIS system. Even with 150 contacts, however, the menu interaction on the turbo system is responsive. Since the display becomes very crowded with more than about 150 contacts displayed, the operator will probably choose to more restrictively filter the display. Once the contacts are filtered out, the speed of the display loop improves. For this reason it is felt that the system makes the appropriate tradeoff.

F. OTHER INTERFACES CONSIDERED

Many workstations have a set of push buttons that can be programmed to perform functions in a manner similar to menu selections. This type of interface is familiar to many operators of current Navy display systems, so the use of function buttons was considered for this project. However, the menu/pointing device combination has the following advantages over buttons.

- Menus are not as limited in space for functional descriptions as pushbuttons. Therefore they can be made more self explanatory.
- Menus can be implemented on the same display screen as the main display thus allowing the operator to keep his attention focused on his situation picture.
- Menus can be more easily changed than most forms of pushbuttons. To change a menu, it is a simple matter of changing a few lines of computer code.
- The same display device can be used to run different applications programs without the need to change the labels on pushbuttons.

Since this system's focus is on meeting the needs of a military decision maker, it is felt that the usability of a menu-driven system is a real benefit.

G. MENU INTERACTION JUSTIFICATION

Many menu systems currently in the commercial marketplace utilize a slightly different user interaction method. For many systems, the pushing and the releasing of the mouse button are each treated as separate events. With this type of interface a

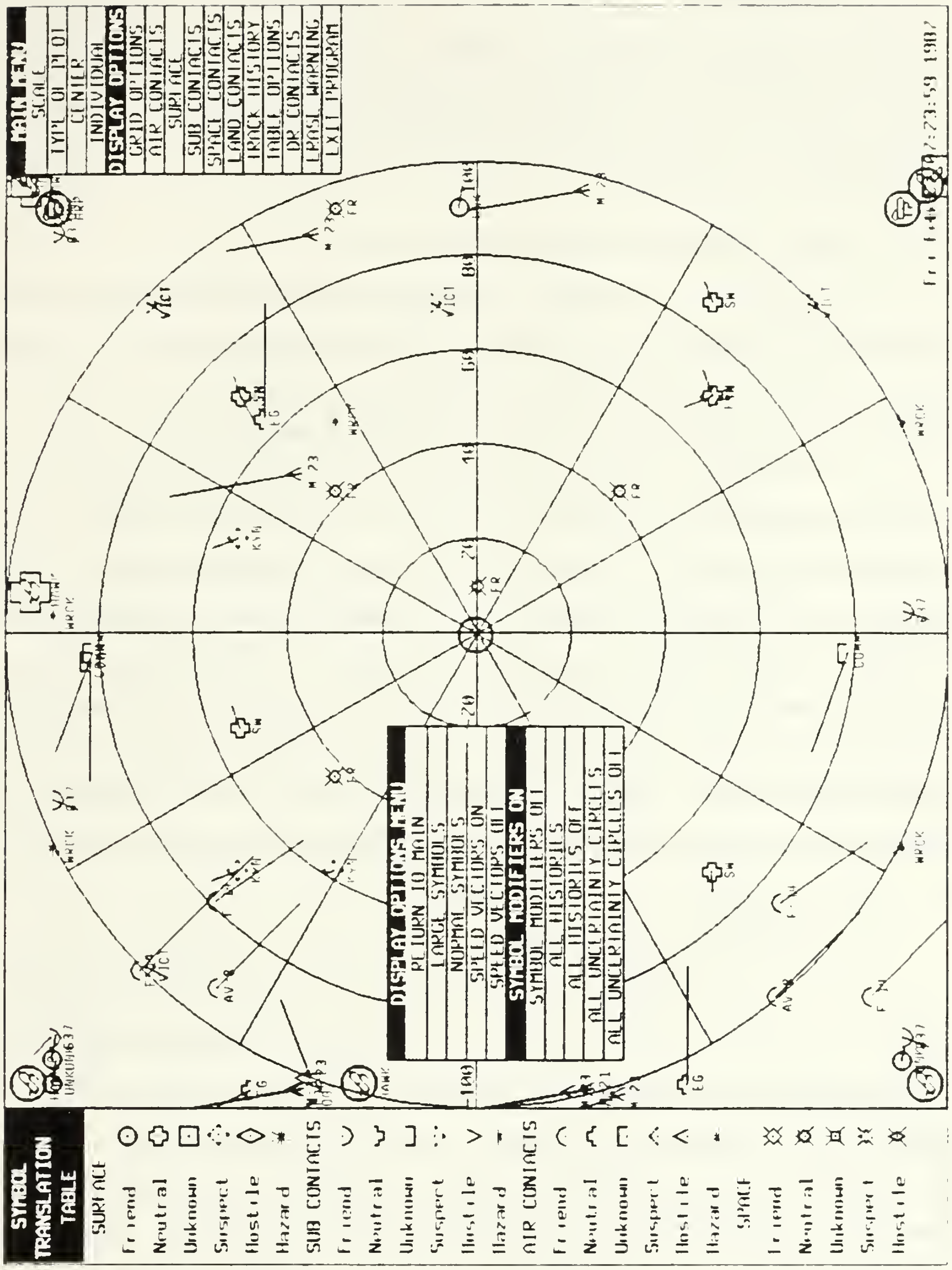


Figure 4.1 Display With A Popup Menu Activated.

push of the mouse displays the menu and its release performs the selection. While this can be faster than requiring one push to display the menu and another push to make a selection, it is felt that the selection of the menu item should require a separate action. This prevents the disconcerting feeling that one gets when the display does something unexpected due to an accidental action. This method more closely emulates the way that one operates a system with push buttons. By setting up the interface this way it is hoped that the best features of both push buttons and menu pointing device combinations are realized.

H. LIMITATIONS OF THE MOUSE

The choice of a mouse for a pointing device is not necessarily the best one for a command and control display system, especially one with a naval emphasis. A mouse would be an inappropriate choice for any system that might be located in a moving platform since it may become a projectile if a sudden movement occurs. Additionally, the movement of the mouse requires that a certain amount of space be available with a surface suitable for giving positive control of the mouse wheel. This is not always available, especially in frequently overcrowded command centers. The mouse was chosen for this project because it is the device available for the workstations chosen. However, the system can be used with a variety of pointing devices as long as there are buttons associated with the device. A more appropriate choice could be an imbedded trackball or a touch sensitive panel. From a software point of view, there is little difference between a mouse and these other pointing devices. They can each handle the logical operations of locating, picking, and menu selection [Ref. 6: p. 164].

I. SUMMARY

Part of the computing power of the workstation has been dedicated to making the display system simple to use. The choice of a menu driven system reflects the fact that the operators of command and control systems have better ways of spending their time other than learning a complex set of computer commands. The use of popup menus prevents the interface from consuming an unreasonable share of the display screen. By slightly modifying the interface used by many popular menu systems, the benefits of older pushbutton technology has been combined with that of the menu driven system.

V. USERS GUIDE

A. GENERAL

The system is available on both IRIS 1 and IRIS 2 in the Graphics and Video Laboratory of the Department of Computer Science at the Naval Postgraduate School. The program is written in the C programming language which is the language of choice for graphics workstations. The use of C gives the system a possibility of greater portability since it has been implemented on a wide variety of computer systems. It is a high-level, structured language that fully supports the use of a modular program design. One of the useful features of C, that was used extensively in the CDS program, is its ability to handle flexible data structure definitions. By using this capability, pieces of information that are logically related can be easily accessed as a single entity. This single feature saved many hours of system development time.

The system is started by typing the command *csquare* on either of the two systems. The program starts the server process on a remote machine and then starts the communications process running. The loading of the fonts into memory takes a short period of time and then the display becomes visible. A polar grid is superimposed on the display. The center of this grid represents the geographic reference point to which all contact position reports refer. This point is known as the data link reference point (DLRP). The initial view that is seen is illustrated by Figure 5.1. Within a few seconds, the display begins receiving contact reports and displaying the appropriate symbols, modifiers, and speed vectors. Figure 5.2 provides a sample of what the display looks like after receiving a set of contact reports.

B. AVAILABLE FUNCTIONS

1. Symbol Filtering

A command and control display system should allow the commander to choose the types of contacts that he is interested in seeing. This can prevent the display from becoming overcrowded without the system making arbitrary decisions about what can be shown. Since it is possible that a commander can rapidly change focus as the situation changes, the system should allow rapid changing of the selected filtering. A system that is designed to support the commander in his decision making must be able to keep up with his needs. The Commander's Display System allows this

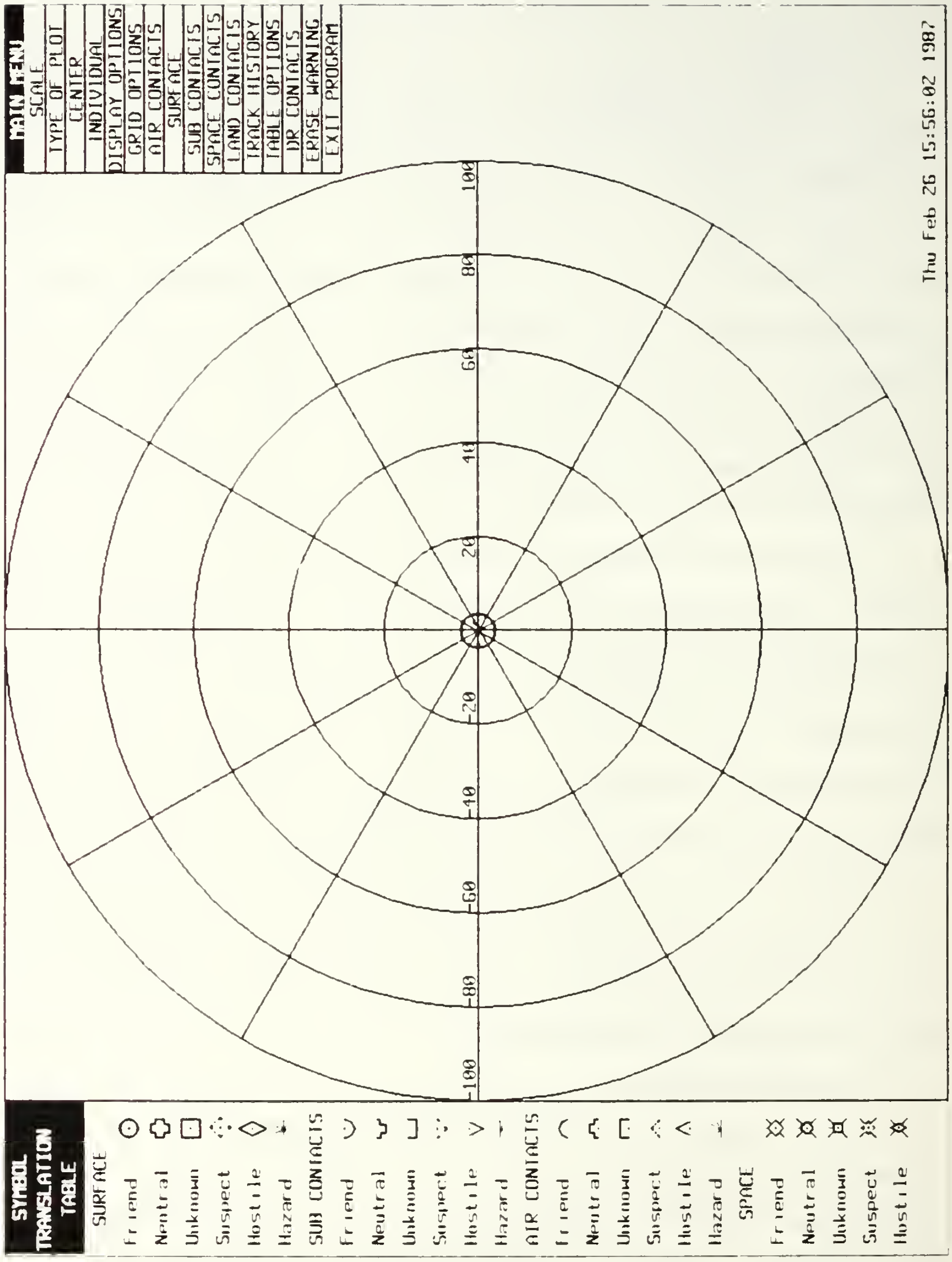


Figure 5.1 Initial Display.

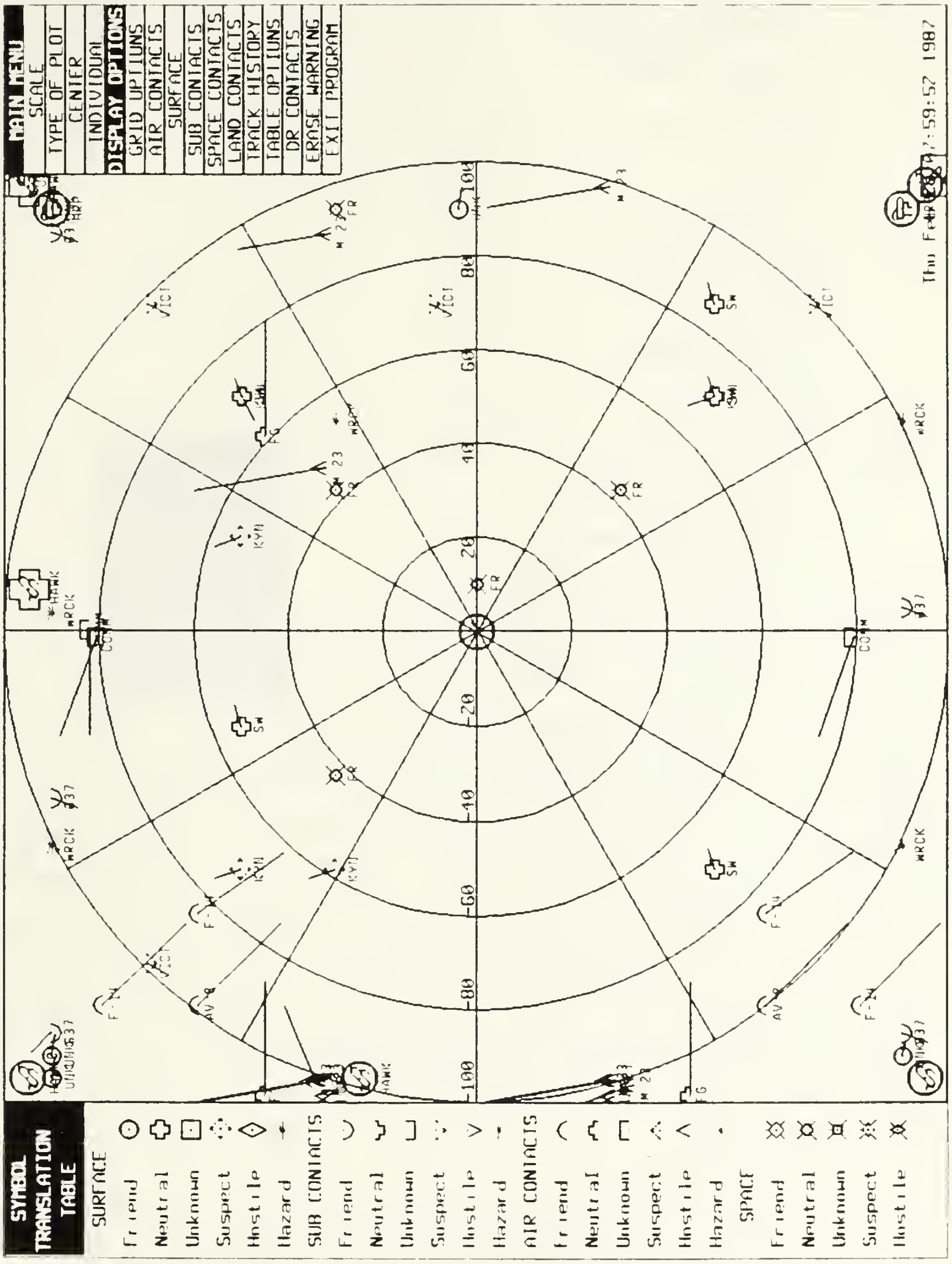


Figure 5.2 Display With Contact Symbols.

type of selection and provides a rapid response. The following types of contacts can be either displayed or kept invisible at the option of the commander in order to tailor the display to his current needs.

- Air Contacts.
- Submarine Contacts
- Surface Contacts
- Space Contacts
- Hazards
- Friendly Contacts
- Hostile Contacts
- Neutral Contacts
- Suspect Contacts
- Land Contacts

These different options can be combined in various ways so the number of available displays is almost unlimited.

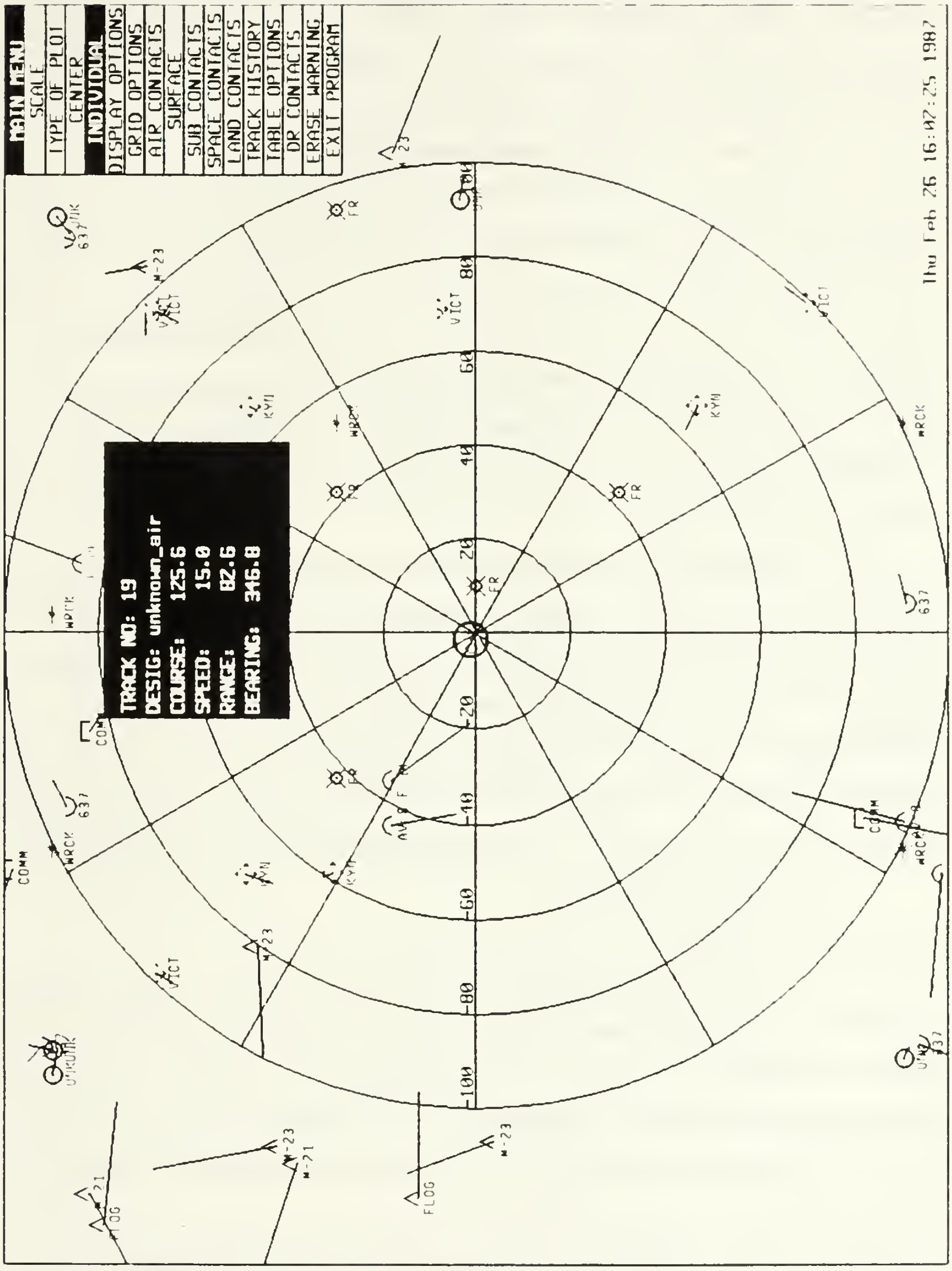
2. Additional Information

a. Summary Information Boxes

It is not possible to visually code all of the information about a complex situation that may be of interest to a decision maker. Therefore, it is important that amplifying information be made available in a simple and rapid fashion. The CDS program does not attempt to implement a large data base; those already exist. Instead, the system makes several functions available to illustrate how easy it can be to make certain types of inquiries on a graphics based system. The Summary Information function allows the user to point at a contact's symbol and click a mouse button in order to display a small box of information about the contact. When the information is no longer desired, the box can be made to disappear with a second click of the button. Figure 5.3 shows a CDS display with a summary information box activated. The amount of information available at the commander's fingertips can be greatly enhanced by a scheme such as this.

b. Track History

A very useful piece of information for a commander trying to understand his situation is a history that tells how the situation developed. This can allow him to use previous trends to help him predict the future movements of the forces that concern him. The CDS provides a rudimentary ability to perform this function by



TRACK NO: 19
DESIG: unknown_air
COURSE: 125.6
SPEED: 15.0
RANGE: 82.6
BEARING: 346.8

Thu Feb 26 16:07:25 1987

Figure 5.3 CDS Display With Summary Information.

allowing the operator to display a dotted line which represents the track that each contact has travelled since it was first reported. The operator can choose to display all contact track histories or he can individually select the option for certain forces of interest. There is also an option which selects the interval between each stored position. The system can store up to 120 points for each contact so the interval chosen determines how long the history is saved.

c. Dead Reckoning And Position Uncertainty

During the period of time between each contact update from the data stream, the system performs what is known as dead reckoning (DR) for each contact. That is, the contact's position on the screen is updated each time through the display loop based on its last reported position, course, speed, and the elapsed time since the update. This provides the commander with the current best estimate of position and it is especially useful for fast moving contacts. The position of the contact, however, becomes more and more of an approximation as the time since the update increases. [Ref. 10: p. 114]

The system provides a mechanism for showing this position uncertainty by the use of circles. These circles are centered at the last reported position for the contact and their radii are based on an assumed speed for the contact. This speed is chosen based on whether the contact is a ship, submarine, or aircraft. These uncertainty circles can be turned on for all contacts or only for those of special interest. Watching the circles grow and collapse can give the operator a good feel for how rapidly new information is being received from his data source.

3. Scaling and Centering

a. Scaling

Any useful display system has some means of controlling the scale of the area that is being displayed. Many systems, however, limit the user to preset scales, often controlled by a switch. With modern graphics systems, controlling the scale of a display is simply a matter of changing the transformation matrix that the system uses to map the coordinates of the world being pictured onto the display screen. The Geometry Engines on the IRIS machines are matrix multipliers that can make the calculations associated with this change almost instantaneously [Ref. 11: p. C-1]. The CDS gives the user a preselected set of scales and an ability to continuously vary the scale or "zoom" the display. This gives greater flexibility; one can imagine a situation where a larger scale might be desired to allow for less clutter but the next highest preset scale eliminates a contact of particular interest.

b. Centering

Another feature that is desirable for a situation display is the ability to change the center of the display. The CDS offers the user the choice of shifting the display in any of the four major axis, moving the display around with the cursor, or centering the display on an area pointed to by the cursor when the left mouse button is pushed. Additionally, the operator can chose to display the plot in a relative mode that keeps one's own ship in the screen center. By a combination of scaling and centering, it is possible to display a maximum scale picture of a crowded section of the display. This feature allows commanders to rapidly focus their attention in any sector of interest.

4. Selectable Symbol Size

The symbol set that was implemented for this project makes use of the ease with which modern computers can handle many different fonts. Each of the symbols is defined as a character in a font, so changing the size of the symbols is simply a matter of selecting a different font. Two different sizes of symbols were created for this project by the use of a simple font editor; the creation of other sizes of fonts is easily possible. Each symbol usually has a modifier displayed below it. It was felt that if the operator desired to see larger symbols, he would probably want to see a larger size font for the modifiers. Therefore, the size of the modifier font is approximately doubled when the larger symbol set is selected. The large symbol size allows the display to be viewed from across a medium sized room, while the small symbols allow many more contacts to be displayed without overlapping.

5. Clutter Reduction

The above discussion of symbol filtering shows one way that the clutter on the screen can be reduced. Often, however, the outright elimination of displayed contacts may not be the most appropriate means of reducing the complexity of the situation picture. It may be that a better method for the particular situation is to display less information about each contact. The Commander's Display System provides several options that allow the display to be made more readable at the expense of showing less information.

- Speed Vectors - these vectors from each contact give a quick indication of the current speed and direction of all displayed contacts. If they are in the way, however, they can be turned off.
- Symbol Modifiers - the symbol modifiers can provide much useful information in a concise fashion. However, they may also be turned off if it is felt that they are interfering with the understanding of the picture.

- Uncertainty Circles - these give the operator some additional information, but they are not intended for continuous display. They can be activated for all contacts or just for those of interest by pointing at the contact's symbol. They can just as easily be turned off.
- Track History - again, these histories are information that does not need to be displayed constantly. All track histories can be turned on or specified contacts of interest can have their histories displayed by pointing at them. They can just as easily be turned off.
- Symbol Translation Table - this table is intended for quick reference only and should not normally be displayed. It is simple to access and remove.
- Grid - the polar grid display gives a frame of reference for the display and shows the scale. However, if it is in the way, it can be turned off and later turned on.
- Main Menu - although the main menu is normally displayed, it can be turned off if desired. To do this, simply point at the title block of the menu and click the middle mouse button. To return the menu, do the same thing over again.

If the display gets too crowded, it is therefore possible to turn off all items that are considered to be of lesser importance. In fact, it is possible to eliminate everything from the display with the exception of the main menu title block.

C. SUMMARY

The various means of display control are meant to be used dynamically, and the combination altered as the tactical situation changes. Since the system is able to make all of the possible changes rapidly, a commander need not worry about losing his display for a period of time while the display changes. By having a responsive system that includes its own processing power, the commander will not be limited to the type of tactical picture that a far removed system designer has chosen for him. He will be able to tailor the display to meet his needs and the special circumstances that he must face. This type of capability can go a long way in helping a military decision maker choose his best course of action with the greatest amount of support from his command and control system.

VI. CONCLUSIONS, LIMITATIONS, AND FUTURE WORK

A. CONCLUSIONS

The goal of this research effort was to demonstrate a possible application for the recent advances in computer graphics workstations in a command and control environment. In addition, a framework was developed upon which to base future efforts in this area. The equipment that was used for the project is a general purpose computing system that has some specialized hardware and software aimed at producing high-resolution, real-time, color graphics displays. The software that was produced shows that such a system can indeed be used to compile a stream of contact reports into a timely, understandable, situation display. This tactical picture can then be tailored to support the decision making process of a military commander in a wide range of scenarios. Since these systems can be purchased for less than $40,000, there is an opportunity to upgrade or replace current systems without spending vast sums of money.

B. LIMITATIONS

Since this project was essentially a one man effort spread over less than six months, there are some limitations on the capabilities of the software that was produced.

- The system does not have a mapping function, although it is well within the hardware capacity of the chosen system to support both outline and shaded region maps.
- There are many useful functions available on current command and control display systems that have not been implemented. One specific example is the computation of the closest point of approach (CPA) of surface contacts.
- There is no ability to locally enter contact reports or to enter data from more than one source. This capability, however, can be added with an extension of the current program structure.
- Due to security considerations, the system has not been designed with the specific data structure of any existing system. In the C programming language, however, data structures are quite flexible and easily changed.

Notwithstanding these limitations, the system can provide the basis for future work. In order to make full use of the available technology, perhaps the next step could be the extension of the CDS into a prototype system that can use real data and be tested in an operational environment.

C. FUTURE WORK

The Commander's Display System makes use of only a small percentage of the capacity of the currently available color graphics hardware. Some specific suggestions for future enhancements to the system are:

- Incorporate some of the Defense Mapping Agency's digital maps. The use of these maps can give a commander valuable information about his environment and the threats to his forces.
- Develop a methodology for the display of more information about the capabilities of displayed platforms. A suggestion is to give the commander the ability to show shaded arcs representing sensor or weapons employment ranges.
- Utilize the communications capacity of networked computer systems more fully by providing a function which allows the creation and transmittal of message traffic in a window on the screen while still maintaining an updated tactical picture.

The list of graphics workstation applications in the command and control area can continue, especially if one considers the capacity of the systems to produce realistic pictures or images. Suffice it to say that the introduction of reasonably priced, high-resolution, raster display systems presents an opportunity to provide commanders with a vast amount of information in an understandable and usable fashion. This technology must be exploited so that our commanders can choose their courses of action with the best possible understanding of both his own force capabilities, and those of the forces which oppose him. Since our commander's decisions can have a large impact on the course of history, it is imperative that they be able to make those decisions with the best available information. Using a high performance workstation with a high resolution color display to produce a clear tactical picture, in real time, can help meet this goal of providing the best possible support to our military leaders.

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